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Acoustics — Measurement of sound emitted by road vehicles of category M and N at standstill and low speed operation — Engineering method

Acoustique — Mesurage du bruit émis par les véhicules routiers de catégories M et N à l'arrêt et en fonctionnement à basse vitesse — Méthode d'expertise

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Contents

Page

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*, in collaboration with ISO/TC 22, *Road vehicles*.

Introduction

The advent of road transport vehicles that rely, in whole or in part, on alternative drive trains (e.g. electromotive propulsion) are serving to reduce both air and noise pollution and their adverse impacts on citizens throughout the world. However, the environmental benefits achieved to date by these “hybrid or pure electric” road vehicles have resulted in the unintended consequence of removing a source of audible signal that is used by various groups of pedestrians (e.g. in particular, blind and low vision persons) to detect the approach, presence and/or departure of road vehicles.

Therefore, this International Standard has been developed to provide a method to measure the sound emission of road vehicles in standstill and low speed operation, as well as to quantify the characteristics of any external sound-generation system installed for the purpose of conveying acoustic information about the approach, presence and/or departure of the vehicle to nearby pedestrians.

This International Standard was developed in cooperation with the Society of Automotive Engineers (SAE) Vehicle Sound for Pedestrians Subcommittee.

Acoustics — Measurement of sound emitted by road vehicles of category M and N at standstill and low speed operation — Engineering method

1 Scope

This International Standard is derived from ISO 362-1 and specifies an engineering method for measuring the sound emitted by M and N category road vehicles at standstill and low speed operating conditions. The specifications reproduce the level of sound which is generated by the principal vehicle sound sources consistent with stationary and low speed vehicle operating conditions relevant for pedestrian safety. The method is designed to meet the requirements of simplicity as far as they are consistent with reproducibility of results under the operating conditions of the vehicle.

The test method requires an acoustic environment which is only obtained in an extensive open space. Such conditions usually exist during the following:

— measurements of vehicles for regulatory certification;

— measurements at the manufacturing stage;

— measurements at official testing stations.

The results obtained by this method give an objective measure of the sound emitted under the specified conditions of test. It is necessary to consider the fact that the subjective appraisal of the annoyance, perceptibility, and/or detectability of different motor vehicles or classes of motor vehicles due to their sound emission are not simply related to the indications of a sound measurement system. As annoyance, perceptibility and/or detectability are strongly related to personal human perception, physiological human condition, culture, and environmental conditions, there are large variations and therefore these terms are not useful as parameters to describe a specific vehicle condition.

Spot checks of vehicles chosen at random rarely occur in an ideal acoustic environment. If measurements are carried out on the road in an acoustic environment which does not fulfil the requirements stated in this International Standard, the results obtained might deviate appreciably from the results obtained using the specified conditions.

In addition, this International Standard provides an engineering method to measure the performance of external sound generation systems intended for the purpose of providing acoustic information to pedestrians on a vehicle's operating condition. This information is reported as objective criteria related to the external sound generation system's sound pressure level, frequency content, and changes in sound pressure level and frequency content as a function of vehicle speed. As such, these measures can provide pedestrians with information on the location, speed, acceleration, and deceleration behaviour of a vehicle. Annex A contains background information relevant in the development of this International Standard.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 362–1, *Measurement of noise emitted by accelerating road vehicles — Engineering method — Part 1: M and N categories*

ISO 10844, *Acoustics — Specification of test tracks for measuring noise emitted by road vehicles and their tyres*

ISO 26101, *Acoustics — Test methods for the qualification of free-field environments*

IEC 60942, *Electroacoustics — Sound calibrators*

IEC 61260–1, *Electroacoustics — Octave-band and fractional-octave-band filters — Part 1: Specifications*

IEC 61672–1, *Electroacoustics — Sound level meters — Part 1: Specifications*

SAE J2889–1, *Measurement of Minimum Noise Emitted by Road Vehicles*

ISO/IEC Guide 98–3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 362–1 and SAE J2889–1 and the following apply.

3.1
front reference plane
vertical plane tangent to the leading edge of the vehicle

3.2
rear reference plane
vertical plane tangent to the trailing edge of the vehicle

3.3
external sound generation system
system that provides an acoustic signal to the external environment of the vehicle for the purpose to provide information to pedestrians

3.4
component
external sound generation system (3.3) intended to emit sound information which can be tested separately from the vehicle

3.5
kerb mass
complete shipping mass of a vehicle fitted with all equipment necessary for normal operation plus the mass of the following elements for M1, N1 and M2 having a maximum authorized mass not exceeding 3 500 kg:

— lubricants, coolant (if needed), washer fluid;

— fuel (tank filled to at least 90 % of the capacity specified by the manufacturer);

— other equipment if included as basic parts for the vehicle, such as spare wheel(s), wheel chocks, fire extinguisher(s), spare parts and tool kit

Note 1 to entry: The definition of kerb mass can vary from country to country, but in this International Standard it refers to the definition contained in ISO 1176.

Note 2 to entry: M and N vehicle categories are defined in SAE J2889–1 and ISO 362-1.

3.6
mass in running order
nominal mass of an N2, N3 or M2 vehicle having a maximum authorized mass greater than 3 500 kg, or an M3 vehicle as determined by the following conditions:

a) the mass in running order is taken as the sum of the unladen vehicle mass and the driver's mass;

b) in the case of category M2 and M3 vehicles that include seating positions for additional crewmembers, their mass is incorporated in the same way and equal to that of the driver

Note 1 to entry: The driver's mass is calculated in accordance with ISO 2416.

Note 2 to entry: Unladen vehicle mass is defined in ISO 362-1.

3.7
full vehicle operation
operation of a vehicle with all systems and components operating according to the manufacturer's specification for normal road use

3.8
simulated vehicle operation
operation of a vehicle with some systems or components disabled to reduce noise interference during testing which may include external signals applied to the vehicle to simulate actual in-use signals

3.9
lowest frequency of interest
frequency below which there is no signal content relevant to the measurement of sound emission for the vehicle under test

4 Symbols and abbreviated terms

Table 1 — Symbols and abbreviated terms and the paragraph in which they are first used

Symbol	Unit	Subclause	Explanation
AA′	—	7.1.5.1	Line perpendicular to vehicle travel which indicates the beginning of the zone to record sound pressure level during test.
BB′	—	7.1.5.1	Line perpendicular to vehicle travel which indicates end of the zone to record sound pressure level during test.
δ_1 - δ_7	dB	D.2	Input quantities to allow for any uncertainty in A-weighted sound pressure level.
δ_8 - δ_{14}	dB	D.3	Input quantities to allow for any uncertainty in one-third-octave-band A-weighted sound pressure level.
δ_{15} - δ_{21}	Hz	D.4	Input quantities to allow for any uncertainty in frequency measurement used for the determination of frequency shift.
CC′	—	6.1.3	Centreline of vehicle travel.
$f_{i,\text{speed}}$	Hz	7.2.5.2	Single frequency component of external sound generation system at a given vehicle speed.
$f_{i,\text{ref}}$	Hz	7.2.5.2	Single frequency component of external sound generation system at reference vehicle speed.
del_f	%	7.2.5.2	Frequency shift expressed in percent of a reference frequency.
Δf	Hz	7.2.3	Frequency resolution of narrowband analysis used to measure frequency spectra for the purpose of determining frequency shift information.
F_s	Hz	5.1.1	Sampling frequency used by digital signal processing system
j	—	6.3.2	Index for single test run within stopped or slow speed cruise test conditions
l_{vehicle}	m	6.1.3	Vehicle length used for determination of minimal space necessary to fulfil hemi-anechoic space requirements.
$L_{\text{st,fwd}}$	dB	7.1.8	Vehicle A-weighted sound pressure level in stationary forward condition.

Table 1 *(continued)*

Symbol	Unit	Subclause	Explanation
$L_{st,rev}$	dB	7.1.8	Vehicle A-weighted sound pressure level in stationary reverse condition.
$L_{crs,10}$	dB	7.1.9	Cruise vehicle A-weighted sound pressure level at a vehicle speed of 10 km/h.
L_{corr}	dB	6.3.2	Background noise correction.
$L_{test,j}$	dB	6.3.2	A-weighted sound pressure level result of j^{th} test run.
$L_{testcorr,j}$	dB	6.3.2	A-weighted sound pressure level result of j^{th} test run corrected for background noise.
L_{bgn}	dB	6.3.1	Background noise A-weighted sound pressure level.
$\Delta L_{bgn,p\text{-}p}$	dB	6.3.1	Range of maximum to minimum value of the representative background noise A-weighted sound pressure level over a defined time period.
L_x	dB	D.2	A-weighted sound pressure level for any stationary or cruise condition for use in assessment of measurement uncertainty.
$L_{x,band}$	dB	D.3	A-weighted sound pressure level per one-third-octave band for any stationary or cruise condition for use in assessment of measurement uncertainty.
$L_{x,meas}$	dB	D.2	A-weighted sound pressure level for any stationary or cruise condition for use in assessment of measurement uncertainty.
ΔL	dB	6.3.2	A-weighted sound pressure level of j^{th} test result minus the A-weighted background noise level ($\Delta L = L_{test,j} - L_{bgn}$).
N	—	7.2.3	Block size of digital sample used for discrete Fourier transform or autopower spectrum analysis.
PP′	—	7.1.1	Line perpendicular to vehicle travel which indicates location of microphones.
$v_{AA'}$	km/h	5.2	Vehicle velocity when vehicle front reference plane in forward motion passes line AA′. See 3.1 for definition of front reference plane.
$v_{BB'}$	km/h	5.2	Vehicle velocity when vehicle front reference plane or rear of vehicle in forward motion passes line BB′. See 3.1 for definition of front reference plane.
$v_{PP'}$	km/h	5.2	Vehicle velocity when vehicle front reference plane in forward motion passes line PP′. See 3.1 for definition of front reference plane.
v_{ref}	km/h	7.2.5.2	Reference vehicle velocity used for calculating frequency shift percentage.
v_{test}	km/h	7.1.5.2	Target vehicle test velocity.

5 Instrumentation

5.1 Instruments for acoustic measurement

5.1.1 General

The apparatus used for measuring the sound pressure level shall be a sound level meter or equivalent measurement system meeting the requirements of class 1 instruments (inclusive of the recommended windscreen, if used). These requirements are described in IEC 61672–1.

The entire measurement system shall be checked by means of a sound calibrator that fulfils the requirements of class 1 sound calibrators in accordance with IEC 60942.

Measurements shall be carried out using the time weighting “F” of the acoustic measurement instrument and the “A” frequency weighting also described in IEC 61672–1. When using a system that includes a periodic monitoring of the A-weighted sound pressure level, a reading should be made at a time interval not greater than 30 ms.

When measurements are carried out for one-third octaves, the instrumentation shall meet all requirements of IEC 61260–1, class 1.

When measurements are carried out for frequency shift, the digital sound recording system shall have at least a 16 bit quantization. The sampling rate, F_S, and the dynamic range shall be appropriate to the signal of interest.

The instruments shall be maintained and calibrated in accordance to the instructions of the instrument manufacturer.

5.1.2 Calibration

At the beginning and at the end of every measurement session, the entire acoustic measurement system shall be checked by means of a sound calibrator as described in 5.1.1. Without any further adjustment, the difference between the readings shall be less than or equal to 0,5 dB. If this value is exceeded, the results of the measurements obtained after the previous satisfactory check shall be discarded.

5.1.3 Compliance with requirements

Compliance of the sound calibrator with the requirements of IEC 60942 shall be verified once a year. Compliance of the instrumentation system with the requirements of IEC 61672–1 shall be verified at least every 2 years. All compliance testing shall be conducted by a laboratory which is authorized to perform calibrations traceable to the appropriate standards.

5.2 Instrumentation for speed measurements

The road speed of the vehicle shall be measured with instruments meeting specification limits of at least ±0,5 km/h when using continuous measuring devices.

If testing uses independent measurements of speed, this instrumentation shall meet specification limits of at least ±0,2 km/h.

NOTE Independent measurements of speed are when two or more separate devices will determine the $v_{AA'}$, $v_{BB'}$ and $v_{PP'}$ values. A continuous measuring device will determine all required speed information with one device.

5.3 Meteorological instrumentation

The meteorological instrumentation used to monitor the environmental conditions during the test shall meet the specifications of the following:

— ±1 °C or less for a temperature measuring device;

— ±1,0 m/s for a wind speed-measuring device;

— ±5 hPa for a barometric pressure measuring device;

— ±5 % for a relative humidity measuring device.

6 Acoustic environment, meteorological conditions, and background noise

6.1 Test site

6.1.1 General

The specifications for the test site provide the necessary acoustic environment to carry out the full vehicle or component tests documented in this International Standard. Outdoor and indoor test environments that meet the specifications of this International Standard provide equivalent acoustic environments and produce results that are equally valid.

6.1.2 Outdoor testing

The test site shall be substantially level. The test track construction and surface shall meet the requirements of ISO 10844. Figure 1 gives information on test site dimensions.

Within a radius of 50 m around the centre of the track, the space shall be free of large reflecting objects, such as fences, rocks, bridges or buildings. The test track and the surface of the site shall be dry and free from absorbing materials, such as powdery snow or loose debris.

In the vicinity of the microphones, there shall be no obstacle that could influence the acoustic field and no person shall remain between the microphone and the noise source. The meter observer shall be positioned so as not to influence the meter reading.

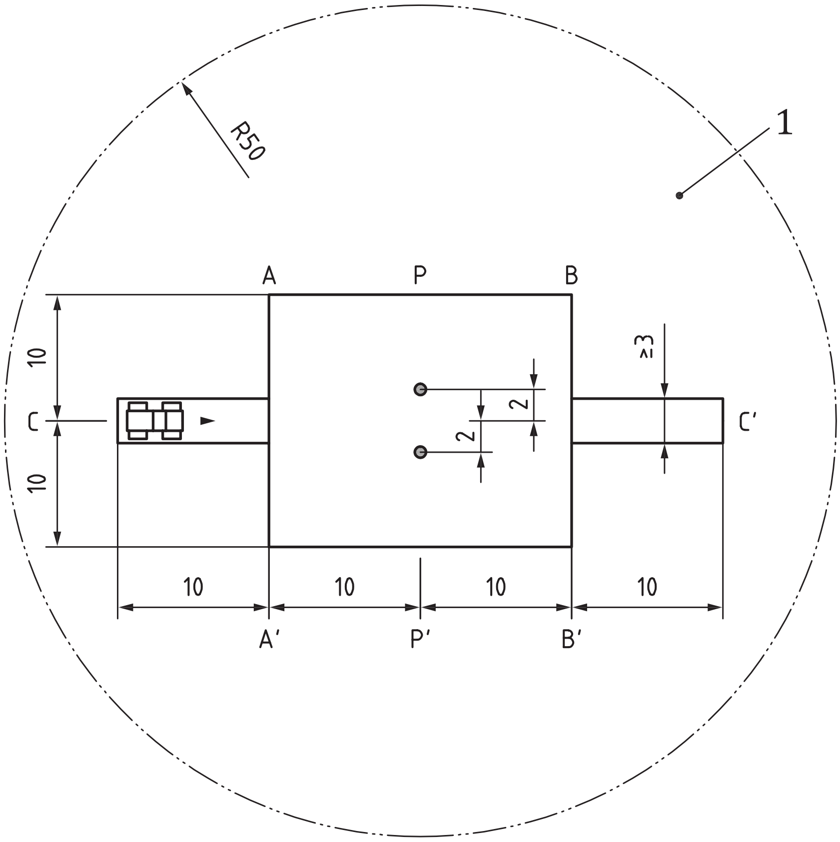
NOTE 1 Buildings outside the 50 m radius might have significant influence if their reflection focuses on the test track.

The term “substantially level” is intended to convey that the test site shall not have slopes or discontinuities that would render invalid the assumption the site provided free-field acoustic propagation. This is not to limit slopes on the test site necessary for water management, drainage, etc. Engineering judgement is expected to be applied to determine the effect on the site of any obstacle. The test track itself is subject to the requirements specified.

For the purpose of this International Standard, test track constructions and surfaces according to either ISO 10844:2011 or ISO 10844:1994 will also provide satisfactory results for vehicle speeds of up to 20 km/h.

NOTE 2 Government regulations can require specific surface requirements.

Dimensions in metres



Key

1 area free of reflecting objects

● microphone (height 1,2 m)

NOTE The shaded area is the minimum area to be covered with a surface complying with ISO 10844.

Figure 1 — Test site dimensions

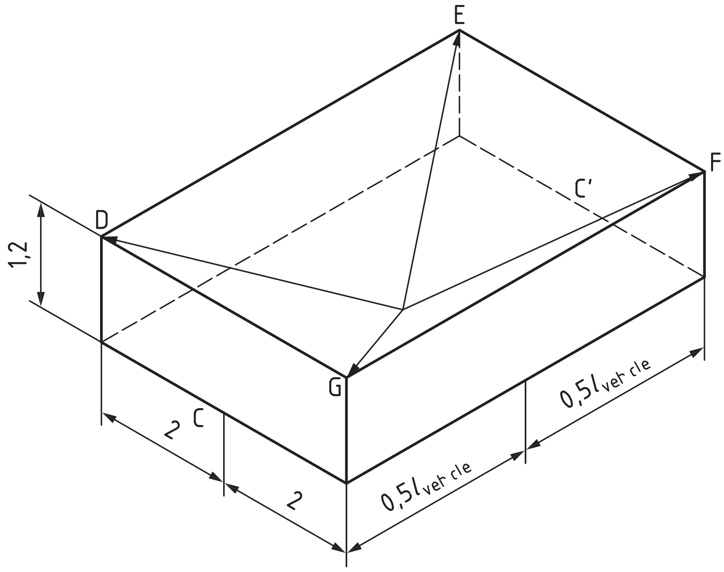
6.1.3 Indoor hemi anechoic or anechoic testing

This subclause specifies conditions applicable when testing a full vehicle, either operating as it would on the road with all systems operational or operating in a mode where only the external sound generation system is operational.

The test facility shall meet requirements of ISO 26101 with the following qualification criteria and measurement requirements appropriate to this test method.

Space to be deemed hemi-anechoic shall be defined as shown in Figure 2. Points D, E, F and G are locations used for the microphones in conducting testing according to the method described in Clause 7.

Dimensions in metres



Key

CC' centreline of vehicle travel

D, E, F, G microphone positions

Figure 2 — Spatial dimensions for acoustic space defined to be hemi-anechoic

For qualifying the hemi acoustic space, the following evaluation shall be conducted:

- sound source location shall be placed on the floor in middle of the space deemed to be anechoic;
- sound source shall provide a broadband input for measurement;
- evaluation shall be conducted in one-third-octave bands;
- microphone locations for evaluation shall be on a line from the source location to each position of microphones used for measurement in the International Standard shown by points D, E, F, and G in Figure 2. This is commonly referred at the microphone transverse;
- the maximum spacing of the measurement points for evaluation on the microphone transverse line shall depend on the size of the space deemed hemi-anechoic. A minimum of 10 points shall be used;
- the one-third-octave bands used to establish hemi-anechoic qualification shall be defined to cover the spectral range of interest.

The test facility shall have a cut-off frequency, as defined in ISO 26101, lower than the lowest frequency of interest.

In the vicinity of the microphones, there shall be no obstacle that could influence the acoustic field and no person shall remain between the microphone and the noise source. The meter observer shall be positioned so as not to influence the meter reading. Microphones shall be located as specified in Figure 1.

NOTE It is expected that users of this International Standard will understand that valid measurements can only be made when the cut-off frequency is lower than the lowest frequency of interest. A specific numerical requirement for cut-off frequency is not given due to the range of variation of appropriate cut-off frequencies depending upon the measured vehicle.

In the absence of any information on the range of frequencies to be measured for hemi-anechoic qualification, it is recommended to use the frequency range from 100 Hz to 10 000 Hz.

6.1.4 Indoor external sound generation system testing

This subclause specifies conditions applicable when testing only the external sound generation system separate from the vehicle.

The test facility shall meet the requirements of ISO 26101 following the same qualification criteria used in 6.1.3 with the following exception: The space to be deemed hemi-anechoic shall extend at least 2 m in all radial directions from the centre location used for the source.

The test facility shall have a cut-off frequency lower than the lowest frequency of interest.

In the vicinity of the microphone, there shall be no obstacle that could influence the acoustic field and no person shall remain between the microphone and the noise source. The meter observer shall be positioned so as not to influence the meter reading. Microphones shall be located as specified in 7.1.1.

6.2 Meteorological conditions

6.2.1 General

Meteorological conditions are specified to provide a range of normal operating temperatures and to prevent abnormal readings due to extreme environmental conditions.

A value representative of temperature, relative humidity, and barometric pressure shall be recorded during the measurement interval.

6.2.2 Outdoor measurements

The meteorological instrumentation shall deliver data representative for the test site and shall be positioned adjacent to the test area at a height representative of the height of the measuring microphone.

The measurements shall be made when the ambient air temperature is within the range from 5 °C to 40 °C.

The ambient temperature may of necessity be restricted to a narrower temperature range such that all key vehicle functionalities that can reduce vehicle noise emissions (e.g. start/stop, hybrid propulsion, battery propulsion, fuel-cell stack operation) are enabled according to manufacturer's specifications.

The tests shall not be carried out if the wind speed, including gusts, at microphone height exceeds 5 m/s during the noise measurement interval.

6.2.3 Indoor measurements

The measurements shall be made when the ambient air temperature is within the range from 5 °C to 40 °C.

The ambient temperature may of necessity be restricted to a narrower temperature range such that all key vehicle functionalities that can reduce vehicle noise emissions (e.g. start/stop, hybrid propulsion, battery propulsion, fuel-cell stack operation) are enabled according to the manufacturer's specifications.

6.3 Background noise

6.3.1 Measurement criteria for A-weighted sound pressure level

The background, or ambient noise, shall be measured for a duration of at least 10 s. A 10 s sample taken from these measurements shall be used to calculate the reported background noise, taking account to ensure the 10 s sample selected is representative of the background noise in absence of any transient disturbance. The measurements shall be made with the same microphones and microphone locations used during the test.

When testing in an indoor facility, the noise emitted by the roller-bench, chassis dynamometer or other test facility equipment, without the vehicle installed or present, inclusive of the noise caused by air handling of facility and vehicle cooling, shall be reported as the background noise. The recorded maximum A-weighted sound pressure level in the selected 10 s samples and from both microphones shall be reported as the background noise, L_{bgn}, along with the maximum to minimum range of the background noise from both microphones, $\Delta L_{bgn,p-p}$.

Figure 3 provides graphical information on the determination of the maximum to minimum range of background noise.

The one-third-octave frequency spectrum measured according to IEC 61260–1, corresponding to the reported maximum level of background noise shall be reported.

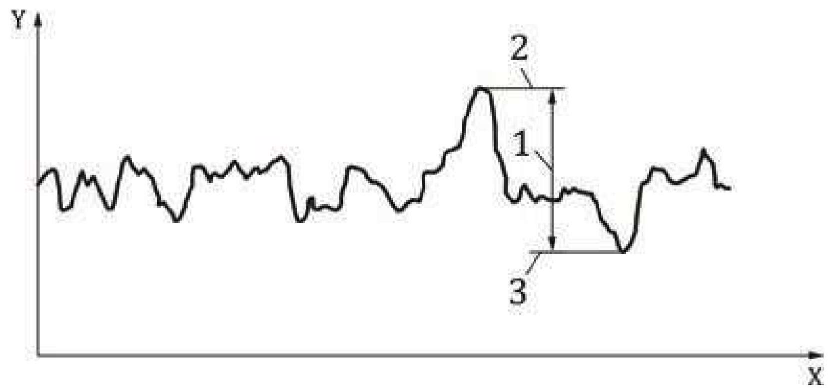
The peak to peak range of the background noise, $\Delta L_{bgn,p-p}$, is determined by subtracting the lowest background noise observed during the 10 s time interval from the largest background noise observed during the 10 s time interval.

When reporting in one-third octaves is required, the background noise shall meet the requirements given in 6.3.3.

Annex G gives measurement criteria for A-weighted sound pressure levels in flowchart form as an aid to measurement and reporting results.

NOTE 1 Background noise measurements account for the variations in time at both microphones. The intent of the above statement is to capture the entire range of variation experienced at the test facility to provide an assessment of the suitability of the test facility to carry out the specified measurements.

NOTE 2 The range of background noise, $\Delta L_{bgn,p-p}$, is specified to ensure the background noise is sufficiently time invariant, meaning, in an acoustic sense the variation in sound pressure level vs. time is low enough, to be able to apply the background corrections of Table 2 to A-weighted sound pressure levels. One-third-octave measurements do not have the necessary background noise time invariance to allow for compensation.



Key

1 range of the background noise level, $\Delta L_{bgn,p-p}$

2 maximum noise level during background noise check

3 minimum noise level during background noise check

X time

Y background noise level

Figure 3 — Determination of the range of background noise

6.3.2 Vehicle A-weighted sound pressure level measurement correction criteria

Depending on the level and the range of maximum to minimum value of the representative background noise A-weighted sound pressure level over a defined time period, the measured j^{th} test result within a test condition, $L_{test,j}$, shall be corrected according to Table 2 to obtain the background noise corrected level $L_{testcorr,j}$. Except where noted, $L_{testcorr,j} = L_{test,j} - L_{corr}$.

Table 2 — Correction for level of background noise when measuring full vehicle A-weighted sound pressure level

Correction for background noise		
Range of maximum to minimum value of the representative background noise A-weighted sound pressure level over a defined time period, $\Delta L_{bgn,p\text{-}p}$, in dB	**Sound pressure level of** j^{th} **test result minus background noise level,** $\Delta L = L_{test,j} - L_{bgn}$, in dB	**Correction,** L_{corr}, in dB
Not applicable	$\Delta L \geq 10$	0
≤2	$8 \leq \Delta L < 10$	0,5
	$6 \leq \Delta L < 8$	1,0
	$4{,}5 \leq \Delta L < 6$	1,5
	$3 \leq \Delta L < 4{,}5$	2,5
	$\Delta L < 3$ dB	No valid measurement can be reported

The trained technician should ensure that measurements are only performed when there is no transient disturbance that could potentially result in an inappropriate noise correction.

Background noise corrections to measurements are only valid when the range of the maximum to minimum background noise A-weighted sound pressure level is 2 dB or less. In all cases where the range of the maximum to minimum background noise is greater than 2 dB, the maximum level of the background noise shall be 10 dB or more below the level of the measurement. When the maximum to minimum range of background noise is greater than 2 dB and the level of the background noise is less than 10 dB below the measurement, no valid measurement is possible.

Background compensation is not permitted for one-third-octave-band measurements.

The use of indoor test facilities may be necessary to achieve the specifications in this International Standard.

Annex H gives correction criteria for A-weighted sound pressure levels in flowchart form as an aid to measurement and reporting results.

NOTE The requirements for margin between background noise and test results are given to maintain an uncertainty of 1 dB or less solely due to background noise. Total measurement uncertainty will include uncertainty due to additional factors.

6.3.3 Background noise requirements when analysing in one-third-octave bands

When reporting one-third octaves according to this International Standard, the level of background noise in each one-third-octave of interest, analysed according to 6.3.1, shall be at least 6 dB below the measurement of the vehicle or external sound generation system under test in each one-third-octave-band of interest. The A-weighted sound pressure level of the background noise shall be at least 10 dB below the measurement of the vehicle or external sound generation system under test.

Background compensation is not permitted for one-third-octave-band measurements.

Annex I gives measurement criteria for 1/3 octave sound pressure levels in flowchart form as an aid to measurement and reporting results.

NOTE The requirements for margin between background noise and test results are given to maintain an uncertainty of 1 dB or less solely due to background noise. Total measurement uncertainty will include uncertainty due to additional factors.

6.3.4 Measurement background noise when testing a component

When measuring an external sound generation system separate from the vehicle as provided in this International Standard, the background noise level shall be at least 10 dB lower than the measured level of the component under test.

The background, or ambient noise, shall be measured for a duration of at least 10 s before and after a series of component tests. A 10 s sample taken from this measurement shall be used to calculate the reported background noise, taking account to ensure the 10-s sample selected is representative of the background noise in absence of any transient disturbance. The measurements shall be made with the same microphones and microphone locations used during the test.

For measurements where narrowband results are reported, the narrowband background noise shall be reported at the same frequency resolution as the measurement results.

7 Test procedures

7.1 Full vehicle testing

7.1.1 Microphone positions

The distance from the microphone positions on the microphone line PP′ to the perpendicular reference line CC′ as specified in Figure 1 on the test track or in an indoor test facility shall be 2,0 m ± 0,05 m.

The microphones shall be located 1,2 m ± 0,02 m above the ground level. The reference direction for free field conditions as specified in IEC 61672–1 shall be horizontal and directed perpendicularly towards the path of the vehicle line CC′.

7.1.2 Conditions of the vehicle

7.1.2.1 General conditions

The vehicle shall be supplied as specified by the vehicle manufacturer.

Before the measurements are started, the vehicle shall be brought to its normal operating conditions.

7.1.2.2 Battery state of charge

If so equipped, propulsion batteries shall have a state-of-charge sufficiently high to enable all key functionalities according to the manufacturer's specifications. Propulsion batteries shall be within their component-temperature window to enable all key functionalities that could reduce vehicle noise emissions. Any other type of rechargeable energy storage system shall be ready to operate during the test.

7.1.2.3 Accessory loads

If the vehicle is equipped with an internal combustion engine and a second source of propulsive power, all vehicle loads that may automatically force an engine re-start or prevent engine shut down shall be switched off.

All audio, entertainment, communication, and navigation systems shall be switched off.

NOTE Example loads could include air conditioning, defroster operation, window de-icing, seat heaters or coolers, etc.

7.1.2.4 Multi-mode operation

If the vehicle is equipped with multiple driver selectable operating modes, the mode which provides the lowest sound emission during the test conditions given in 7.1.5 shall be selected.

When the vehicle provides multiple operating modes that are automatically selected by the vehicle, it is the responsibility of the manufacturer to determine the correct manner of testing to achieve the minimum sound emission.

In cases where it is not possible to determine the vehicle operating mode providing the lowest sound emission, all modes shall be tested and the mode giving the lowest test result shall be used to report the vehicle sound emission in accordance with this International Standard.

NOTE Modes include, but are not limited to: engine operation state (on or off), driver selectable operating modes (sport, eco, winter, etc.), vehicle selectable operating modes (sport, eco, winter, etc.), and transmission selection mode (sport, eco, winter, etc.). Modes do not include transmission gear selection such as park, drive, reverse or neutral.

7.1.2.5 Vehicle non-pedestrian safety warning signals

No sound or noise source not related to pedestrian safety shall operate during the tests.

The purpose of this requirement is to ensure no sound or noise source not related to pedestrian safety shall operate during the test.

7.1.3 Test mass of vehicle

Measurements shall be made on vehicles at kerb mass +75 kg or mass in running order, as defined by the manufacturer, with an allowable tolerance of ±15 %.

7.1.4 Tyre selection and condition

The tyres for test are selected by the vehicle manufacturer and shall correspond to one of the tyre sizes and types designated for the vehicle by the vehicle manufacturer.

The tyres shall be inflated to the pressure recommended by the vehicle manufacturer for the test mass of the vehicle.

NOTE Tyre noise will contribute to the sound emission of the vehicle at any speed over 0 km/h. At vehicle speeds in excess of 20 km/h, tyre noise will have a significant contribution to measured sound pressure levels.

7.1.5 Operating conditions

7.1.5.1 General conditions

The path of the centreline of the vehicle shall follow line CC′ as closely as possible throughout the entire test, from the approach to line AA′ until the rear of the vehicle passes line BB′. Any trailer, which is not readily separable from the towing vehicle, shall be ignored when considering the crossing of the line BB′.

7.1.5.2 Test speeds

The vehicle shall reach the test speed, v_{test}, when the front reference plane according to the definition given in 3.1 is at line PP′. During the constant speed test, the acceleration control unit shall be positioned to maintain a constant speed between AA′ and BB′. The vehicle shall be operated as defined by the manufacturer for normal operation.

Normal operation may include shutoff of one or more propulsion sources.

7.1.5.3 Standstill conditions

7.1.5.3.1 General

The test speed, v_{test}, shall be 0 km/h with the front reference plane or rear reference plane, as appropriate, on the PP′ line.

If the vehicle is equipped with an internal combustion engine and a second source of propulsive power, the stopped condition test measurement shall be made after a time delay from the vehicle stopped condition to allow engine shutdown, and before vehicle loads can force an engine re-start.

7.1.5.3.2 Forward testing

For forward testing, the front reference plane of the vehicle shall be on the PP′ line.

7.1.5.3.3 Backing testing

For backing testing, the rear reference plane of the vehicle shall be on the PP′ line.

7.1.5.3.4 Manual transmission vehicle

The vehicle shall be tested in the appropriate standstill mode as defined in 7.1.2.4. The gear selector shall be in a gear and the vehicle shall remain at 0 km/h for the duration of the test. The manufacturer shall determine the appropriate condition for testing.

NOTE The common situation for stopped vehicle testing would be for a manual transmission vehicle to have the gear selector in neutral. However, for the purpose of this test, the intention is to place the vehicle in a state where it is ready to move.

7.1.5.3.5 Automatic transmission vehicle

The vehicle shall be tested in the appropriate standstill mode as defined in 7.1.2.4. The gear selector shall be in the normal driving position for testing when the front reference plane of the vehicle is on the PP′ line. The gear selector shall be in the reverse driving position for testing when the rear reference plane of the vehicle is on the PP′ line. The vehicle shall remain at 0 km/h for the duration of the test. The manufacturer shall determine the appropriate condition for testing.

7.1.5.4 Slow speed cruise

7.1.5.4.1 General

If a vehicle is tested in an indoor facility, the vehicle shall be located with the front or rear reference plane on the PP′ line, as appropriate. The vehicle A-weighted sound pressure level shall be measured for a duration of 5 s and reported. The one-third-octave frequency spectrum corresponding to the reported maximum A-weighted sound pressure level shall be reported.

For the purpose of measuring the performance of an external sound generation system, the sound pressure level of the vehicle may be measured with the vehicle at 0 km/h and external sound generation system controlled as to simulate operation at 10 km/h.

7.1.5.4.2 Automatic transmission vehicle

The gear selector shall be placed as specified by the manufacturer for normal driving.

7.1.5.4.3 Manual transmission vehicle

The gear selector shall be placed in the highest gear which can achieve the target vehicle speed with constant engine speed.

7.1.5.4.4 Forward testing at 10 km/h

The test speed, v_{test}, shall be 10 km/h ± 1 km/h between AA′ and PP′.

It is recommended that if other vehicle speeds are specified in regulations, the performance specification given here can be modified to change the test speed, retaining all other specifications.

7.1.6 Measurement readings and reported values

7.1.6.1 General

It is recommended that persons technically trained and experienced in current noise measurement techniques select the test instrumentation and conduct the tests.

If a sound peak obviously out of character with the general sound pressure level is observed, that measurement shall be discarded.

At least four measurements for all test conditions shall be made on each side of the vehicle and for each mode tested.

The first four j^{th} valid consecutive measurement results for any test condition, within 2,0 dB, allowing for the deletion of non-valid results, shall be used for the calculation of the appropriate intermediate or final result.

For measurement of a vehicle in motion (forward and backing) outdoors, the maximum A-weighted sound pressure level indicated during each passage of the vehicle between AA′ and PP′ ($L_{\text{test},j}$) shall be noted for each microphone position, to the first significant digit after the decimal place (for example, XX,X).

For measurement of a vehicle in motion indoor and in standstill (forward and backing), the maximum A-weighted sound pressure level indicated during each period of 5 s defined in 7.1.5.4.1 for each microphone position, $L_{\text{test},j}$, shall be noted, to the first significant digit after the decimal place (for example, XX,X).

NOTE 1 Satisfying the criteria listed above requires evaluation of measured sound pressure data vs. time to select the appropriate time segments for proper analysis and reporting of measured values according to this International Standard.

NOTE 2 An intermediate result can be for one vehicle mode or operating condition.

7.1.6.2 Measurement of a vehicle in standstill conditions

This subclause specifies the requirements to measure the vehicle sound emission in standstill conditions.

The vehicle sound pressure level shall be measured for a duration of 5 s.

For each maximum A-weighted sound pressure level for each microphone position, the corresponding one-third-octave results for each microphone position shall be reported.

7.1.6.3 Measurement of a vehicle in motion

7.1.6.3.1 General

This subclause specifies the requirements to measure the vehicle sound emission in motion.

7.1.6.3.2 Outdoor testing

For each maximum A-weighted sound pressure level, the corresponding one-third-octave spectrum shall be reported for each microphone position.

7.1.6.3.3 Indoor testing

The vehicle sound pressure level shall be measured for a duration of 5 s.

If a sound peak obviously out of character with the general sound pressure level is observed, that measurement shall be discarded. The selected sound sample shall be representative of the vehicle minimum sound emission in the condition of test in absence of any transient disturbance. $L_{test,j}$ for each microphone position shall be corrected according to the criteria given in 6.3.2 to obtain $L_{testcorr,j}$.

For each maximum A-weighted sound pressure level, the corresponding one-third-octave spectrum shall be reported for each microphone position.

7.1.7 Data compilation

7.1.7.1 Maximum A-weighted sound pressure level data compilation

For a given test condition and mode (see 7.1.2.4), the background-corrected results, $L_{testcorr,j}$ of the runs shall be averaged separately for each side.

The reported A-weighted sound pressure level is the lower value of the two averages, rounded to the nearest integer.

7.1.7.2 One-third-octave sound pressure level data compilation

The one-third-octave reported spectrum shall be the arithmetic average of the four individual run one-third-octave spectra corresponding to the maximum A-weighted sound pressure level on each side for each individual measurement run.

The final one-third-octave spectra, measured according to IEC 61260–1, to be reported are the spectra corresponding to the same side as the reported A-weighted sound pressure level.

No background correction shall be applied to any measured one-third-octave result.

Any one-third-octave spectrum measured when the conditions of 6.3.3 are not satisfied may only be reported for information and the measurement uncertainties given in Table 4 are not valid.

7.1.8 Standstill results

The $L_{st,fwd}$ and $L_{st,rev}$ value for each mode according to 7.1.2.4 shall be the result from 7.1.5.3 using the definitions given in 7.1.6.

If one-third-octave bands are analysed, they shall use the result given in 7.1.7.2.

7.1.9 Slow speed cruise result at 10 km/h

The $L_{crs,10}$ value for each mode according to 7.1.2.4 shall be the result from 7.1.5.4 using the definitions given in 7.1.6.

If one-third-octave bands are analysed, they shall use the result given in 7.1.7.2.

7.1.10 Reported value

The reported value $L_{crs,10}$, $L_{st,rev}$ and $L_{st,fwd}$ shall be the minimum of the $L_{crs,10}$, $L_{st,rev}$ and $L_{st,fwd}$, values for each mode according to 7.1.2.4.

7.2 Measurement of sound to determine frequency shift

7.2.1 General

The specifications contained in these sections are intended to measure the emitted acoustic information from an external sound generation system installed for purposes of providing acoustic information to pedestrians in the near vicinity of a vehicle. The information so measured characterizes the frequencies emitted by the system, as well as the change in frequency as a function of vehicle operating parameters.

No background correction shall be applied to any measured result.

See Annex B for further information on frequency shift.

7.2.2 Instrumentation

The entire acoustic measurement system including microphone(s) and any subsequent measurement apparatus shall fulfil the requirements of IEC 61672–1, class 1 sound level meter.

The digital sound recording system shall have at least a 16 bit quantization. The sampling rate, F_S, and the dynamic range shall be appropriate to the signal of interest.

NOTE No specific requirements have been given for sampling rate due to the wide range of signal frequency content that may be analysed. It is expected that knowledgeable and trained personnel will select appropriate sampling rates.

7.2.3 Signal processing requirements

The frequency resolution, Δf, of the measurement shall be sufficiently precise to differentiate between the frequencies at the various test conditions. The sound analysis system shall be capable of performing discrete Fourier transform and auto power spectrum analysis at a frequency resolution and over the frequency range containing all frequencies of interest. The block size, N, used for subsequent signal processing shall enable the required Δf, where $\Delta f \leq F_S/N$.

Analyser settings shall be determined by the user to provide data according to these requirements.

7.2.4 Test facilities

7.2.4.1 Vehicle test facilities

The test facility shall meet the requirements given in 6.1.2 or 6.1.3.

7.2.4.2 Component test facilities

The test facility shall meet the requirements given in 6.1.4.

The sound emitting component of the external sound generation system is recommended to be mounted 0,5 m above a reflecting plane (floor) of the test space. The primary propagation axis of the sound emitting component shall be oriented horizontal to the reflecting plane.

The microphone is recommended to be located 1,0 m from the centre of the component at a height of 0,5 m.

NOTE Specific recommendations have been given for placement of the external sound generation system and the microphone within the test facility to provide guidance for successful testing. There are other arrangements of the external sound generation system and microphone that can be effective to measure frequency content.

7.2.5 Frequency shift measurement test procedure

7.2.5.1 General

7.2.5.1.1 Frequency shift measurements

The frequency shift shall be measured by a vehicle, a simulated vehicle operation, or a component based test procedure.

7.2.5.1.2 Full vehicle operation

The vehicle shall be installed in an indoor test facility where the vehicle can operate in the same manner as outdoors. All microphone locations shall be as for the full vehicle test conditions as specified in Figure 1. The front plane of the vehicle shall be on the PP′ line.

Outdoor variant: The vehicle shall be operated in the same outdoor test facility and according to the same general operating condition as for the full vehicle testing (see 7.1). The microphone shall be installed on board of the vehicle in the direct vicinity of the emitting surface of the external sound generating system. The acquisition system shall be installed on board of the vehicle.

A frequency, f_i, shall be identified that is intended to change as a function of vehicle speed, which can be measured and can be tracked for operating conditions specified in this International Standard.

Special care shall be taken to carry out the frequency shifting measurements in outdoor facilities with the vehicle in motion. The signal intended to be measured should not be masked by other vehicle or background noise.

NOTE 1 Typical signal analysis tools provide frequency vs. speed of the tonal component(s) that correspond with vehicle speed.

NOTE 2 No specific frequency identification process has been specified as there is no known identification specification that can clearly identify frequencies which shift with vehicle operating conditions, primarily vehicle speed, when the frequency content of the desired signal and any background noise is unknown. See Annex B for further information.

NOTE 3 It is understood when using an indoor test facility that the vehicle will remain in position relative to the microphones. This is for the purpose to provide an acoustically stationary signal for subsequent analysis and reporting of results.

On board microphones do not have relative motion from the sound generation system and deliver a more reliable signal for frequency shifting measurement. For on-board microphone installed in the direct vicinity of the emitting surface of the external sound generating system, it is recommended

— to position the microphones on the axis (if it exists) of the acoustic emission of the system;

— at a distance of 8 cm from the emitting surface: not too far to be influenced by other sound sources, and not too close to have no any distorted signal;

— to use a decoupling attachment device between microphone and vehicle body.

Special care shall be taken to perform the frequency shifting measurements in indoor facilities with the tyres rotating. This is due to the contaminating signal from the tyre/roll interface.

7.2.5.1.3 Simulated vehicle operation (for indoor or outdoor)

The vehicle shall be operated in a test facility where the vehicle can accept an external vehicle speed signal simulating vehicle operation. All microphone locations shall be as for the full vehicle test conditions as specified in Figure 1. The front reference plane of the vehicle shall be on the PP′ line.

A frequency, f_i, shall be identified that is intended to change as a function of vehicle speed, which can be measured and can be tracked for operating conditions specified in this International Standard.

NOTE 1 Typical signal analysis tools provide frequency vs. speed of the tonal component(s) that correspond with vehicle speed.

NOTE 2 No specific frequency identification process has been specified as there is no known identification specification that can clearly identify frequencies which shift with vehicle operating conditions, primarily vehicle speed, when the frequency content of the desired signal and any background noise is unknown. See Annex B for further information.

NOTE 3 It is understood when using an indoor test facility that the vehicle will remain in position relative to the microphones. This is for the purpose to provide an acoustically stationary signal for subsequent analysis and reporting of results. The use of the simulated operation further removes potentially interfering noise due to the tyre/road interaction.

7.2.5.1.4 Component test procedure

A frequency, f_i, shall be identified that is expected to change as a function of vehicle speed, which can be measured and can be tracked for operating conditions specified in this International Standard.

NOTE Typical signal analysis tools provide frequency vs. speed of the tonal component(s) that correspond with vehicle speed.

7.2.5.2 Measurement procedure

The frequency characteristics of the sound shall be measured together with an input signal to the external sound generation system corresponding to the reference vehicle speed.

The sound output of the system shall be measured as follows.

— Record at least 5 s of the sound at a constant vehicle speed.

— Using a Hanning window, calculate the autopower of the signal with a frequency resolution of at least 1 Hz using at least 66,6 % overlap averages from the 5 s time signal.

The frequencies, $f_{i,\text{speed}}$, of the external sound generation system signal shall be measured and recorded.

The corresponding vehicle speeds, $f_{i,\text{speed}}$ and $f_{i,\text{ref}}$, shall be measured and recorded.

Calculate *del_f*, the frequency shift of the external sound generation system signal according to Formula (1):

$$del\_f = \{[(f_{i,\text{speed}} - \text{fi}_{,\text{ref}})/(v_{\text{test}} - v_{\text{ref}})]/f_{i,\text{ref}}\} \cdot 100 \quad (1)$$

where

$f_{i,\text{speed}}$ is the frequency at a given speed value;

$f_{i,\text{ref}}$ is the frequency at the reference speed value;

v_{test} is the vehicle velocity, actual or simulated, corresponding to the frequency $f_{i,\text{speed}}$;

v_{ref} is the vehicle velocity, actual or simulated, corresponding to the frequency $f_{i,\text{ref}}$.

Formula (1) is only valid when the actual vehicle speed, v_{test}, is higher than the reference vehicle speed, v_{ref}.

Results shall be reported using Table 3.

Table 3 — Vehicle speed for measurement to determine frequency shift

		Test results at target speeds			
		5 km/h (Reference)	10 km/h	15 km/h	20 km/h
Reported speed	km/h				
Frequency, $f_{i,\text{speed}}$, left side	Hz				
Frequency, $f_{i,\text{speed}}$, right side	Hz				
Frequency shift, left side	%	n.a.			
Frequency shift, right side	%	n.a.			

The reference speed should be 5 km/h unless other speeds are desired.

7.3 Measurement uncertainty

The measurement procedure described in 7.1 and 7.2 is affected by several parameters (e.g. environmental conditions, measurement system uncertainty, test speed variation, actual centring of a driven vehicle in the test lane, etc.) that lead to variation in the resulting level observed for the same subject. The source and nature of these perturbations are not completely known and sometimes affect the end result in a non-predictable way. The uncertainty of results obtained from measurements according to this International Standard can be evaluated by the procedure given in ISO/IEC Guide 98-3, or by inter-laboratory comparisons in accordance with ISO 5725 (all parts). Since extensive inter- and intra-laboratory data were not available, the procedure given in ISO/IEC Guide 98-3 was followed to estimate the uncertainty associated with this International Standard. The uncertainties given below are based on existing statistical data, analysis of tolerances stated in this International Standard, and engineering judgement. The uncertainties so determined are grouped as follows:

a) variations expected within the same test laboratory and slight variations in ambient conditions found within a single test series (run-to-run);

b) variations expected within the same test laboratory but with variation in ambient conditions and equipment properties that can normally be expected during the year (day-to-day);

c) variations between test laboratories where, apart from ambient conditions, equipment, staff and road surface conditions are also different (site-to-site).

If reported, the expanded uncertainty together with the corresponding coverage factor for the stated coverage probability of 80 % as defined in ISO/IEC Guide 98-3 shall be given. Information on the determination of the expanded uncertainty is given in Annex D.

NOTE 1 Annex D gives a framework for analysis in accordance with ISO/IEC Guide 98-3, which can be used to conduct future research on measurement uncertainty for this International Standard.

These data are given in Table 4 for three different measurement types. The variability is given for a coverage probability of 80 %. The data express the variability of results for a certain measurement object and do not cover product variation.

Table 4 — Variability of measurement results for a coverage probability of 80 %

Measurement type	Run-to-run	Day-to-day	Site-to-site
A-weighted sound pressure level, in dB (indoor/outdoor)	0,3/0,5	0,5/0,9	1,4
A-weighted one-third-octave sound pressure level, in dB	1,5	2,5	3,5
Frequency shift, in *del_f*	1,0 %	1,0 %	10,0 %

NOTE 2 The measurement uncertainties listed here are the results after averaging the four individual measurement runs of this International Standard. The individual measurement runs will have variation in excess of these values.

NOTE 3 The uncertainties for indoor measurement are taken from ISO 362-3

NOTE 4 The uncertainties for site-to-site measurements are strongly dependent on the vehicle speeds actually used. The uncertainties for outdoor measurements in Table 4 are based on ISO 362-1.

Until more specific knowledge is available, the data for site-to-site variability can be used in test reports to state the expanded measurement uncertainty for a coverage probability of 80 %.

8 Test report

The test report includes the following information:

a) a reference to this International Standard, i.e. ISO 16254;

b) the details of the test site, site orientation, and weather conditions including wind speed, air temperature, wind direction, barometric pressure, and humidity; or if an indoor facility is used, description of the facility, including dimensions and cut-off frequency of facility;

c) the type of measuring equipment, including the windscreen;

d) the A-weighted sound pressure level typical of the background noise;

e) the one-third-octave-band spectrum typical of the background noise;

f) the identification of the vehicle, its engine, its transmission system, including available transmission ratios, size and type of tyres, tyre pressure, tyre production type, power, test mass, vehicle length and location of the front reference plane and rear reference plane;

g) the auxiliary equipment of the vehicle, where appropriate, and its operating conditions;

h) the technology content of the vehicle’s propulsion system (e.g. internal combustion engine, stop/start, battery electric, hybrid, plug-in hybrid, extended-range electric, fuel cell);

i) any special test or vehicle conditions, including operating modes of the vehicle or settings reflective of the technology content listed in h);

j) if a vehicle is being tested to measure the sound emission performance of an external sound generation system, this system shall be noted in the report;

k) all valid A-weighted sound pressure level values measured for each test, listed according to the side of the vehicle and the direction of the vehicle movement on the test site;

l) the final results, $L_{\mathrm{crs,10}}$, $L_{\mathrm{st,rev}}$ and $L_{\mathrm{st,fwd}}$;

m) all valid individual narrowband frequencies measured and all one-third-octave frequency spectra measurements for each test;

n) the expanded measurement uncertainty for a coverage probability of 80 % for each of the measured quantities.

Annex A
(informative)

Information on development of ISO 16254

The development of this International Standard was motivated by the need to measure the minimum noise emission of a motor vehicle in an objective, reproducible, repeatable, and technically correct manner for the purposes of understanding potential safety concerns with low noise emission vehicles. Additional analyses or specification are necessary to provide correlation between the objective measures of vehicle noise emission specified in this International Standard and the subjective evaluation of human subjects to detectability, annoyance, perception, or any other psychoacoustic analysis of sound. Such psychoacoustic parameters are by their very nature subjective parameters that can only be accurately presented as percentages of a given population that will report a response to a certain sound in the presence of a specified background noise.

This test procedure was based on the existing vehicle noise emission test procedures of ISO 362-1 and SAE J2805. These existing noise test procedures for maximum noise emission, which form the technical basis for global vehicle exterior maximum noise regulation, have been developed over the past 50 years to provide objective, reproducible, repeatable, and a technically correct manner for conducting exterior vehicle noise emission measurements. Issues relating to the acoustic characteristics of the measurement site, the road surface used for measurement, the instrumentation used for measurement, the environmental conditions necessary for accurate measurement, and an understanding of the sources of, and bounds on, measurement uncertainty; these have all been considered, developed, and refined in ISO 362-1 and SAE J2805.

To ensure the fitness for purpose of this International Standard, the following adaptations have been made to the ISO 362-1 and SAE J2805 specifications.

a) The microphone location has been moved from 7,5 m to 2,0 m. This change is to improve the signal to noise ratio of the measurement.

b) The specifications on the background (ambient) sound have been extended to provide conditions suitable for the typical sound pressure levels at the vehicle operating conditions specified in this International Standard. Consistent with the use of this International Standard, it is the maximum background sound level that is reported and used for determining the suitability of the test site or in any correction of measured vehicle noise emission levels.

c) The vehicle operating conditions have been modified to conditions representative of both minimum vehicle sound pressure level and conditions where vehicle noise emission is highly likely to cause a safety concern. The conditions so specified cover a wide range of real world conditions of concern and are judged to provide a practical set of conditions suitable for carrying out testing with a reasonable workload.

d) The alternative of using an indoor semi-anechoic space for measurement of the specified zero vehicle speed (stopped) condition has been provided. This was later extended to also include the moving vehicle condition as information was presented to show that the error due to measurement of tyre/road noise on a roll was acceptable. This is in recognition that the necessary ambient noise conditions for accurate vehicle measurement are difficult to obtain in an outdoor space for vehicles with low noise emission in the standstill and moving conditions.

e) The selection of the minimum, as opposed to the maximum, average of the left and right average result for reporting a vehicle test condition result is consistent with the purposes of this International Standard.

f) The selection of the lesser of (minimum) of the vehicle conditions specified as the reported minimum sound emission level of the vehicle is consistent with the purposes of this International

Standard. This applies when testing multiple operating modes according to the details given in 7.1.2.4.

g) When using this International Standard for the purposes of determining the noise emission of a specific external sound pressure generating system, the measurement requirement is specified to use the maximum recorded sound pressure level to provide accurate measurement of both continuous and intermittent sources.

h) The vehicle level test procedure was extended to provide support to determine the change in frequency of a vehicle's emitted sound as a function of vehicle speed or other operating parameters. This is termed the frequency shifting of the sound.

i) This International Standard was extended to be able to measure an ESG system at a component level. Measurements of an external sound generation system at a component level allow for additional accuracy of measurement and control of the background noise level that are typically not available when conducting an outdoor or full vehicle measurement. Component testing measures the frequency content of an ESG system at a sufficient precision to allow for the frequency shift information to be determined.

j) For the purposes of use in a regulation, it may be necessary to determine that additional units of a production process or replacement units are sufficiently similar to an original unit. This evaluation may be accomplished by using the frequency shift measurement procedures and applying the necessary tolerances to the frequency (Hz) information and the level (dB) information. This evaluation may also be accomplished by verifying the respective sound source has identical software.

Annex B
(informative)

Development of frequency shift information

In motor vehicles where combustion engines provide the propulsive power, the sound emission of the vehicle naturally provides information to a pedestrian and the vehicle occupants on the operating state of the vehicle. One primary source of information is the correlation between the frequencies emitted by road vehicles and the velocity of the road vehicle. In broad terms, the acoustic characteristics of the propulsive motor generate higher frequencies at higher vehicle speeds, and humans have come to associate these characteristics to provide information on how fast a vehicle is travelling, or if a vehicle is accelerating.

As the measurement of the frequencies and/or the change of frequencies relative to vehicle speed or other vehicle operating conditions may be useful to characterize necessary pedestrian information, measurement procedures have been provided to accomplish this purpose.

The following assumptions have been taken when developing this test procedure.

a) The persons conducting the test are familiar with the latest acoustic measurement procedures, equipment and standards.

b) The persons conducting the test are trained on the test equipment to be used during the test.

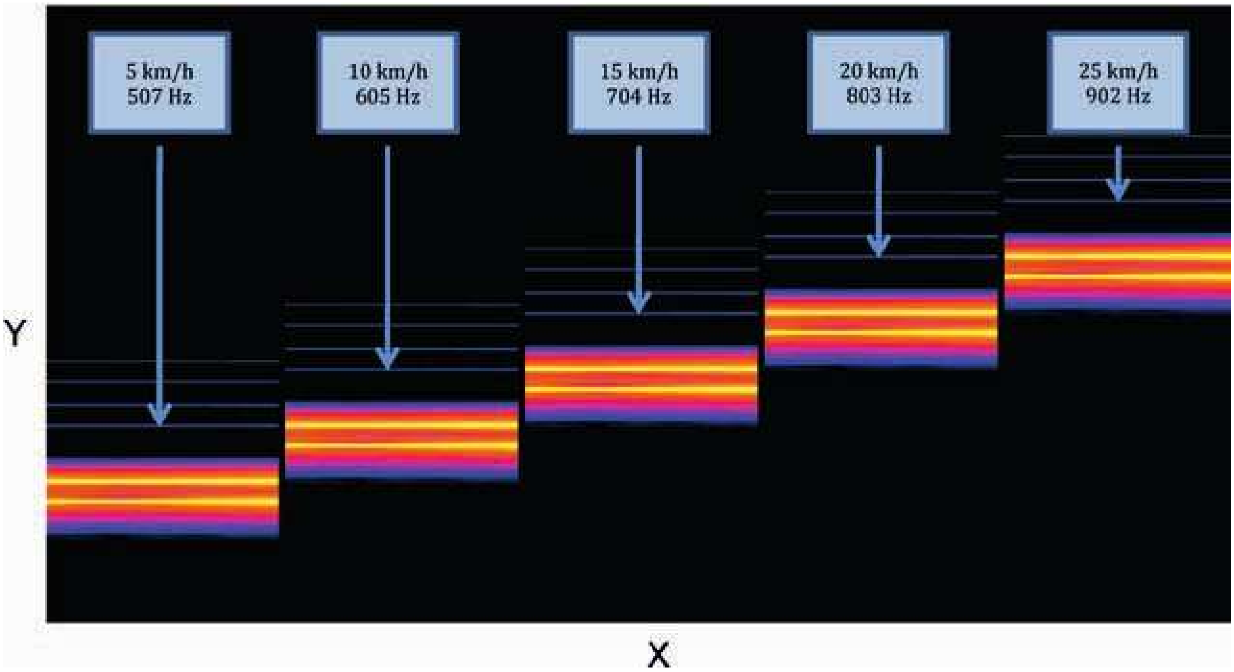
c) There is at least one frequency component that may be tracked as a function of vehicle speed or other vehicle operating condition.

d) The necessary hardware and software is available to simulate vehicle operating conditions where an external sound generation system can be accurately tested as a component.

e) The persons conducting the test know what frequencies should be produced by the external sound generation system or vehicle under measurement.

f) The sound is a stationary signal within all time periods used for measurement.

The procedure is specified as a manual process but may be automated if the measuring equipment provides such capability. The process operates using the same frequency tracking principles as used for rotating machinery order tracking measurements. Figure B.1 provides an example of such a measurement process where multiple frequencies are present, and a single frequency has been chosen to provide the tracking information.



Key

X vehicle speed (km/h)

Y frequency (Hz)

Figure B.1 — Example of measurement of frequency vs. vehicle speed information

Annex C
(informative)

Relevance of objective acoustic data to pedestrian safety

This International Standard provides measurement procedures for the following:

a) A-weighted sound pressure level (SPL) at the full vehicle;

b) one-third-octave frequency information at the full vehicle level;

c) narrowband (1 Hz resolution) frequency information at the full vehicle level;

d) narrowband (1 Hz resolution) frequency information at the component level;

e) the frequency shift of either a full vehicle or a component vs. vehicle speed or other vehicle operating parameter.

In regulatory discussions, the concepts of presence (detection), direction, location, and operation are terms used to attempt to specify the needed information transmitted from the vehicle to the pedestrian, in the case of this International Standard, transmitted by acoustic means. It is recognized that all road vehicles make some acoustic signal; the only relevant question for regulatory authorities is whether the signal is of sufficient magnitude and of a character to allow pedestrians to have necessary acoustic information to enable the pedestrian to travel safely in the presence of road vehicles. In no case has any assumption been made that pedestrians need acoustic information in all cases, and in all places, to allow them to distinguish individual road vehicles.

The primary and reasonable assumption behind the development of this International Standard is to measure the sound emission of vehicles in a range of sound emission that will correspond to road vehicle sound emissions that can be reasonably expected to be heard in a residential situation. In no case is there any expectation that vehicles could be, or should be, heard when loud or unusual noise is present; for example, construction sites, in the presence of vehicles exceeding maximum noise regulatory limits, or in situation where the natural sound level would exceed the level where a person with normal hearing would reasonably expect to hear a road vehicle.

The term “presence” is closely related to the acoustic term “detection”, but is not identical. Detection has a specific meaning and definition in signal processing (acoustic or electromagnetic) of sufficient signal energy in excess of natural or background signal energy. Detection is also (usually) applied to signals of assumed stationary character. Therefore, detection is specifically related to the signal energy present in relation to the background, in this case, the background noise. As this is a vehicle and component measurement standard, detection in a specific situation cannot be assessed. Presence, however, is understood in this context as the ability of a pedestrian to determine a vehicle is nearby. As such, there are multiple objective measurements that contribute to the determination of presence. The first is the A-weighted sound pressure level, the second is the frequency content of the sound emission of the vehicle, and the third is the shifting of the frequency(ies) of the vehicle with respect to the vehicle velocity.

The A-weighted sound pressure level [SPL, with sound pressure in units of Pascal (Pa), and expressed in this International Standard as A-weighted levels expressed in decibels (dB)] provides the necessary sound energy to provide a listener with some sort of audible sound. The frequency or frequencies of the sound emitted by the vehicle provide an additional source if information to pedestrians that can render the underlying SPL more or less effective, depending on the frequencies, and combination of frequencies, present in the signal. Finally, the frequency shifting of the sound signal as a function of the vehicle speed and/or other vehicle operating parameter provides significantly important information to a pedestrian on the vehicle speed; information on the vehicle acceleration or deceleration; and the characteristic of frequency shifting provides the means by which a wide number of undesirable sounds may be excluded from use.

The term “direction” is used in this context to mean the ability of a pedestrian to locate spatially a sound relative to their position. Given the assumption that the sound has been detected, it is the frequency content of the sound signal that will contribute to the accurate spatial location of the vehicle. Of importance to the determination of direction is the large amount of information that can be determined by a pedestrian independent of the sound emitted by the vehicle. This comes from two basic sources: the movement of the vehicle relative to the pedestrian, and the movement of the pedestrian relative to the vehicle.

By the very nature of movement of the vehicle relative to the pedestrian, human hearing processes naturally detect the spatial change of the sound source relative to their current location. From this information, including both changes in amplitude (volume) and changes in relative angle, determinations can be made on the direction and movement of a vehicle. In addition, this process works similarly if the pedestrian moves relative to the vehicle, with the additional source of information that a human can change the orientation of their head relative to the sound, exploiting the binaural hearing capability to provide additional information on the direction of a vehicle.

The term “location” is similar to direction, but in this usage incorporates the additional information of range in addition to spatial orientation. The development of location information uses the same process as used for direction information, with the additional integration of the frequency shifting to provide reinforcing information to the change in sound pressure level, allowing improved determinations if a vehicle is moving closer or further away, and by how much.

The term “operation” is used in this context to mean the pedestrian understanding how the vehicle is being operated by the driver: is the driver moving at a steady speed; is the driver braking quickly or slowing down gradually; or is the driver accelerating the vehicle? This information is provided primarily by the frequency shifting of the vehicle sound, augmented by additional information from the vehicle SPL. From both of these sources of information, a pedestrian can determine the vehicle operation and can therefore make judgments on the action and intent of the driver.

All of the objective criteria specified in this International Standard operate independently as necessary, but not sufficient criteria to provide adequate information to pedestrians. In combination, the criteria of SPL, frequency content, and frequency shifting, provide a set of measures which provide the necessary information to pedestrians to allow them to safely interact with vehicle traffic. Finally, the objective criteria provide a limiting set of specification that may be used by regulatory authorities to enable appropriate sounds to be used and produced.

Annex D
(informative)

Measurement uncertainty — Framework for analysis according to ISO/IEC Guide 98-3 (GUM)

D.1 General

The measurement procedure is affected by several factors causing disturbance that lead to variation in the resulting level observed for the same subject. The source and nature of these perturbations are not completely known and sometimes affect the end result in a non-predictable way. The accepted format for expression of uncertainties generally associated with methods of measurement is that given in ISO/IEC Guide 98-3. This format incorporates an uncertainty budget, in which all the various sources of uncertainty are identified and quantified and from which the combined standard uncertainty can be obtained. Uncertainties are due to the following factors:

— variations in measurement devices, such as sound level meters, calibrators and speed-measuring devices;

— variations in local environmental conditions that affect sound propagation at the time of measurement of $L_{\mathrm{st,fwd}}$, $L_{\mathrm{st,rev}}$,and $L_{x,\mathrm{band}}$;

— variations in vehicle speed and in vehicle position during the pass-by run;

— variations in local environmental conditions that affect the characteristics of the source;

— effect of environmental conditions (air pressure, air density, humidity, air temperature) that influence the mechanical characteristics of the source, mainly engine performance;

— effect of environmental conditions that influence the sound production of the propulsion system (air pressure, air density, humidity, air temperature) and the rolling sound (tyre and road surface temperature, humid surfaces);

— test site properties (test surface texture and absorption, surface gradient).

The uncertainty determined according to 7.3 represents the uncertainty associated with this International Standard. It does not cover the uncertainty associated with the variation in the production processes of the manufacturer. The variations in the sound pressure level or frequency of identical units of a production process are outside the scope of this International Standard.

The uncertainty effects may be grouped in the three areas composed of the following sources (see 7.3):

a) uncertainty due to changes in vehicle operation within consecutive runs, small changes in weather conditions, small changes in background noise levels, and measurement system uncertainty; these are referred to as run-to-run variations;

b) uncertainty due to changes in weather conditions throughout the year, changing properties of a test surface over time, changes in measurement system performance over longer periods and changes in the vehicle operation; these are referred to as day-to-day variations;

c) uncertainty due to different test site locations, measurement systems, road surface characteristics and vehicle operation; these are referred to as site-to-site variations.

The site-to-site variation comprises uncertainty sources from a), b) and c). The day-to-day variation comprises uncertainty sources from a) and b).

D.2 Expression for the calculation of A-weighted sound pressure levels of vehicle low speed operation

The general expression for the calculation of the low speed operation sound pressure level, L_x, is given by Formula (D.1):

$$L_x = L_{x,\mathrm{meas}} + \delta_1 + \delta_2 + \delta_3 + \delta_4 + \delta_5 + \delta_6 + \delta_7 \quad \text{(D.1)}$$

where

$L_{x,\mathrm{meas}}$ is the A-weighted sound pressure level from any relevant test specified in this International Standard;

δ_1 is an input quantity to allow for any uncertainty in the measurement system;

δ_2 is an input quantity to allow for any uncertainty in the environmental conditions that affect sound propagation from the source at the time of measurement;

δ_3 is an input quantity to allow for any uncertainty in the vehicle speed and position;

δ_4 is an input quantity to allow for any uncertainty in the local environmental conditions that affect characteristics of the source;

δ_5 is an input quantity to allow for any uncertainty in the effect of environmental conditions on the mechanical characteristics of the power unit;

δ_6 is an input quantity to allow for any uncertainty in the effect of environmental conditions on the sound production of the propulsion system and the tyre/road noise;

δ_7 is an input quantity to allow for any uncertainty in the effect of test site properties, primarily related to road surface characteristics and surface absorption characteristics.

NOTE 1 The inputs included in Formula (D.1) to allow for errors are those considered applicable according to the state of knowledge at the time when this International Standard was being prepared, but further research could reveal that there are others.

NOTE 2 The estimated values of the delta functions can be principally positive or negative although they are considered to be zero for the given measurement (see Table D.1). Their uncertainties are not additive for the purpose of determining a measurement result.

NOTE 3 The estimated value of δ_7 is a nonlinear function of vehicle speed. It is effectively zero at zero km/h and increases nonlinearly with potential significance on the measurement result at any vehicle speed of 20 km/h or higher.

D.3 Expression for the calculation of one-third-octave-band sound pressure levels of vehicle low speed operation

The general expression for the calculation of the one-third-octave-band sound pressure level at a low speed operation condition, $L_{x,\mathrm{band}}$, is given by Formula (D.2):

$$L_{x,\mathrm{band}} = L_{x,\mathrm{band,meas}} + \delta_8 + \delta_9 + \delta_{10} + \delta_{11} + \delta_{12} + \delta_{13} + \delta_{14} \quad \text{(D.2)}$$

where

$L_{x,\text{band,meas}}$ is the A-weighted one-third-octave-band sound pressure level from any test specified in this International Standard at a band specified in IEC 61260–1;

δ_8 is an input quantity to allow for any uncertainty in the measurement system;

δ_9 is an input quantity to allow for any uncertainty in the environmental conditions that affect sound propagation from the source at the time of measurement;

δ_{10} is an input quantity to allow for any uncertainty in the vehicle speed and position;

δ_{11} is an input quantity to allow for any uncertainty in the local environmental conditions that affect characteristics of the source;

δ_{12} is an input quantity to allow for any uncertainty in the effect of environmental conditions on the mechanical characteristics of the power unit and any external sound generation system;

δ_{13} is an input quantity to allow for any uncertainty in the effect of environmental conditions on the sound production of the propulsion system, any external sound generation system, and the tyre/road noise;

δ_{14} is an input quantity to allow for any uncertainty in the effect of test site properties, primarily related to road surface characteristics and surface absorption characteristics.

NOTE 1 The inputs included in Formula (D.2) to allow for errors are those considered applicable according to the state of knowledge at the time when this International Standard was being prepared, but further research could reveal that there are others.

NOTE 2 The estimated values of the delta functions can be principally positive or negative although they are considered to be zero for the given measurement (see Table D.2). Their uncertainties are not additive for the purpose of determining a measurement result.

NOTE 3 The estimated value of δ_{14} is a nonlinear function of vehicle speed. It is effectively zero at zero km/h and increases nonlinearly with potential significance on the measurement result at any vehicle speed of 20 km/h or greater.

D.4 Expression for the calculation of frequency shift of vehicle low speed operation

The general expression for the calculation of the frequency shift a low speed operation condition, *del_f*, is given by Formula (D.3):

$$del\_f = \{[(f_{i,\text{speed}} - f_{i,\text{ref}})/(v_\text{test} - v_\text{ref})]/f_{i,\text{ref}}\} \cdot 100 + \delta_{15} + \delta_{16} + \delta_{17} + \delta_{18} + \delta_{19} + \delta_{20} + \delta_{21} \quad \text{(D.3)}$$

where

$f_{i,\text{ref}}$ is the frequency identified at the reference vehicle speed which is defined as the reference frequency;

$f_{i,\text{speed}}$ is the frequency identified at any vehicle speed higher than the reference speed which is the shifted reference frequency due to the increase in vehicle speed;

v_test is the actual vehicle speed during the test;

v_ref is the reference vehicle speed from which relative speed changes are calculated;

δ_{15} is an input quantity to allow for any uncertainty in the measurement system;

δ_{16} is an input quantity to allow for any uncertainty in the signal processing functions used for identification of a frequency;

δ_{17} is an input quantity to allow for any uncertainty in the measured vehicle speed;

δ_{18} is an input quantity to allow for any uncertainty in the input of measured vehicle speed to any external sound generation system;

δ_{19} is an input quantity to allow for any uncertainty in the identification of reference or shifted frequencies by the responsible test engineer;

δ_{20} is an input quantity to allow for any uncertainty in the effect of environmental conditions on the sound production of the propulsion system, any external sound generation system, and the tyre/road noise;

δ_{21} is an input quantity to allow for any uncertainty in the effect of test site properties.

NOTE 1 The inputs included in Formula (D.3) to allow for errors are those considered applicable according to the state of knowledge at the time when this International Standard was being prepared, but further research could reveal that there are others.

NOTE 2 The estimated values of the delta functions can be principally positive or negative although they are considered to be zero for the given measurement (see Table D.3). Their uncertainties are not additive for the purpose of determining a measurement result.

D.5 Uncertainty budget for determination of A-weighted sound pressure level

Table D.1 — Uncertainty budget for determination of A-weighted sound pressure level of vehicle low speed operation

Quantity	**Estimate** in dB	**Standard uncertainty,** u_i in dB	**Probability distribution**	**Sensitivity coefficient,** c_i	**Uncertainty contribution,** $u_i c_i$ in dB
$L_{x,\mathrm{meas}}$	L_x	—	—	1	—
δ_1	0	—	—	1	—
δ_2	0	—	—	1	—
δ_3	0	—	—	1	—
δ_4	0	—	—	1	—
δ_5	0	—	—	1	—
δ_6	0	—	—	1	—
δ_7	0	—	—	1	—

From the individual uncertainty contributions, $u_i c_i$, the combined standard uncertainty, u, can be calculated according to the rules of ISO/IEC Guide 98-3, taking into account potential correlations between various input quantities.

NOTE The uncertainty evaluation described represents a framework that provides useful information to users of this International Standard. This information represents the state of technical information at the time when this International Standard was being prepared. Further work is necessary to provide uncertainty information on all terms in Formula (D.1) and all interactions between such terms.

D.6 Uncertainty budget for determination of one-third-octave-band sound pressure levels

Table D.2 — Uncertainty budget for determination of one-third-octave-band sound pressure levels of vehicle low speed operation

Quantity	Estimate in dB	Standard uncertainty, u_i in dB	Probability distribution	Sensitivity coefficient, c_i	Uncertainty contribution, u_ic_i in dB
$L_{x,\text{band,meas}}$	$L_{x,\text{band}}$	—	—	1	—
δ_8	0	—	—	1	—
δ_9	0	—	—	1	—
δ_{10}	0	—	—	1	—
δ_{11}	0	—	—	1	—
δ_{12}	0	—	—	1	—
δ_{13}	0	—	—	1	—
δ_{14}	0	—	—	1	—

From the individual uncertainty contributions, u_ic_i, the combined standard uncertainty, u, can be calculated according to the rules of ISO/IEC Guide 98-3, taking into account potential correlations between various input quantities.

NOTE The uncertainty evaluation described represents a framework that provides useful information to users of this International Standard. This information represents the state of technical information at this time. Further work is necessary to provide uncertainty information on all terms in Formula (D.2) and all interactions between such terms.

D.7 Uncertainty budget for determination of frequency shift

Table D.3 — Uncertainty budget for determination of frequency shift of vehicle low speed operation

Quantity	Estimate in dB	Standard uncertainty, u_i in dB	Probability distribution	Sensitivity coefficient, c_i	Uncertainty contribution, u_ic_i in dB
del_f_{meas}	del_f	—	—	1	—
δ_{15}	0	—	—	1	—
δ_{16}	0	—	—	1	—
δ_{17}	0	—	—	1	—
δ_{18}	0	—	—	1	—
δ_{19}	0	—	—	1	—
δ_{20}	0	—	—	1	—
δ_{21}	0	—	—	1	—

From the individual uncertainty contributions, u_ic_i, the combined standard uncertainty, u, can be calculated according to the rules of ISO/IEC Guide 98-3, taking into account potential correlations between various input quantities.

NOTE The uncertainty evaluation described represents a framework that provides useful information to users of this International Standard. This information represents the state of technical information at this time. Further work is necessary to provide uncertainty information on all terms in Formula (D.3) and all interactions between such terms.

D.8 Expanded uncertainty of measurement

The expanded uncertainty, *U*, is calculated by multiplying the combined standard uncertainty, *u*, by the appropriate coverage factor for the chosen coverage probability as described in ISO/IEC Guide 98-3.

Annex E
(normative)

Testing requirements for reduced uncertainty

Regulatory usage of test procedures is influenced by the administrative processes used by various national and international regulatory authorities. This International Standard was developed with the expectation that it would be utilized in regulatory assessment where the vehicle manufacturer has control over the test location, test equipment, and determines the day of test; however, the test is carried out under direct supervision of governmentally accredited technical authorities. These types of regulatory processes typically also include conformity of production assessment. The combination of these measures ensures the test results represent the actual vehicle performance while applying engineering judgement where necessary. The basic assumption is if the vehicle meets the performance requirements anywhere within the tolerances specified in the test, the vehicle will provide satisfactory performance for all relevant operating conditions.

There are regulatory processes where this is not the case. For the regulatory procedures where a third party will test a vehicle, additional stringency on the test procedure is required to ensure repeatable and reproducible results. In these cases, engineering judgement cannot be applied due to the regulatory process assuming that a vehicle shall meet the regulatory requirements for all combinations of tolerances specified in the test. If a vehicle cannot meet requirement for all possible conditions of test, the vehicle is deemed unsatisfactory and noncompliant with regulatory requirements.

Annex F
(informative)

Frequency identification of tones using the fast Fourier transformation

F.1 General

The fast Fourier transformation or FFT is a powerful and commonly used algorithm to identify the spectral content of sampled time series. The FFT algorithm is to be used with appropriate selected digital signal processing (DSP) parameters in order to guarantee optimal results. The differences in DSP parameters depend on what aspect of the signal needs identification or foreknowledge of some characteristics of the signal to be analysed.

The sampled representation of a signal should not contain frequency content above the Nyquist frequency or half of the sampling frequency. Measurement systems include anti-aliasing filters to guarantee this requirement. The practical implementations of anti-aliasing filters have their cut-off frequency set at 80 % to 90 % of the Nyquist frequency.

Applying an FFT on a block of time data inherently assumes that this block repeats itself over time. This implies that the end of the block continues to the start of the block without any transient behaviour. This is rarely the case and transients can be observed. This effect is referred to as leakage. In order to keep the frequency content as close as possible to the exact frequencies, several time windows have been developed.[7] These windows attenuate the signal on the extremes to minimize effects of transients. The Hanning-, Flattop-, and Rectangular window are commonly used.

For the identification of the frequency shift as a function of vehicle speed, the frequency of one or more tonal components in stationary signals is required.

F.2 Concept

The identification of tonal components requires an observation of the signal for a sufficient time lapse. This is commonly obtained by processing the time series to an averaged power spectrum. This averaged power spectrum is the average of the power spectra of a number of overlapping time blocks.

A power spectrum is the square norm of the FFT spectrum of a time block multiplied with a time window of the same length. The square norm is obtained by the multiplication of that FFT spectrum with its complex conjugate spectrum.

In order to give equal weight to all time samples from a signal energy point of view, the overlap percentage has to be well chosen. This overlap percentage depends on the type of time window.

F.3 Implementation

The sampling frequency of the time series to be analysed should exceed the highest frequency of concern with a factor of 2,5 corresponding to an anti-aliasing filter placed at 80 % of the Nyquist frequency. However, it is recommended to use a higher factor (e.g. 4) to have negligible impact of that filter on the levels of the tonal components of interest.

The size of each time block depends on the frequency resolution that is needed. Tonal components can be identified with sufficient resolution if this component is on a spectral line index 100 or higher. The size of the time block is determined by the lowest frequency of interest.

In order to suppress leakage, the use of the Hanning window is recommended. This window is a compromise between correct amplitude estimation and adequate frequency identification. As a consequence, an overlap factor of around 67 % is known to give equal weight to all time samples of the time series being analysed.

F.4 Example

Assume the case below:

— Minimal frequency of interest: F_{min} = 125 Hz

— Maximum frequency of interest: F_{max} = 2 400 Hz

Minimal sampling frequency:

— $F_s \geq F_{max} \times 4$ = 2 400 Hz × 4 = 9 600 Hz

Minimal duration and size of time block or maximum resolution of the spectrum:

— $T \geq 100/F_{min}$ = 100/125 Hz = 0,8 s

— $B_s = F_s \cdot T$ = 9 600 Hz × 0,8 s = 7 680 samples

— $\Delta F = F_s/B_s$ = 9 600/7 680 = 1,25

A wide number of selections apply to the requirements above. The selected sampling frequency should be equal or higher than the minimal sampling frequency and the frequency resolution equal or smaller than the maximum resolution:

— F_s = 12 800 Hz > 9 600 Hz

— B_s = 16 384 samples

— ΔF = 12 800/16 384 = 0,781 25 < 0,8

— F_{min} is at spectral line 125 Hz/0,781 25 = 160 Hz

Annex G
(informative)

Flowchart of the procedure for measurement and reporting of background noise

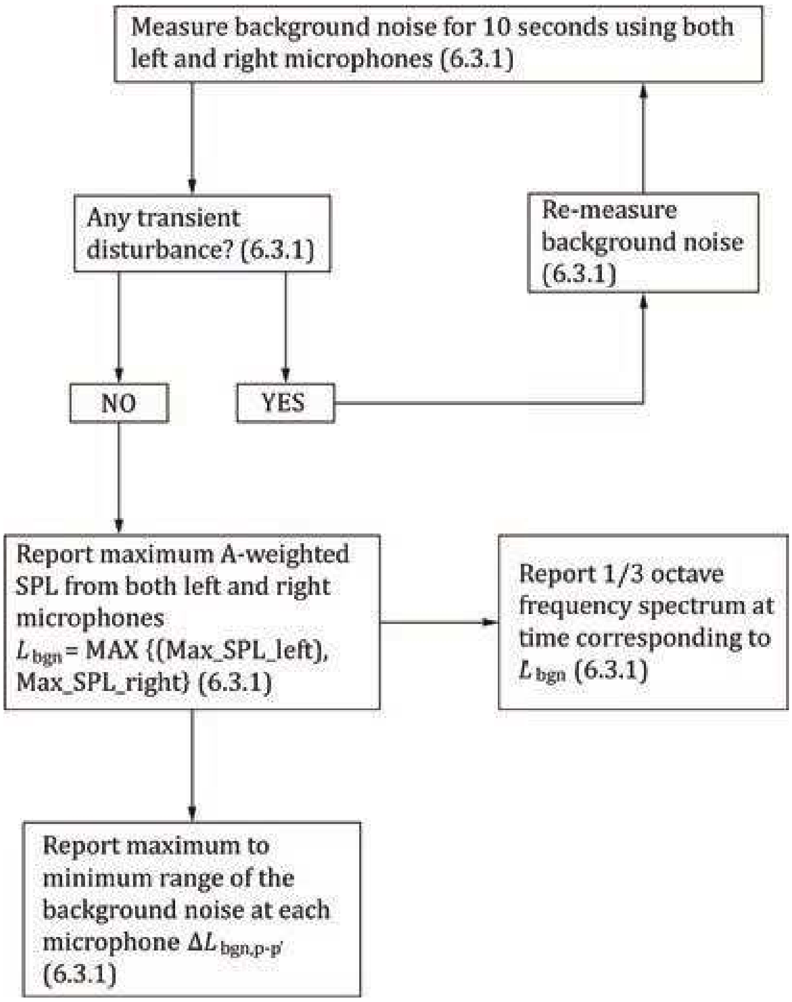


Figure G.1 — Measurement and reporting of background noise

Annex H
(informative)

Flowchart for the procedure to correct A-weighted sound pressure levels

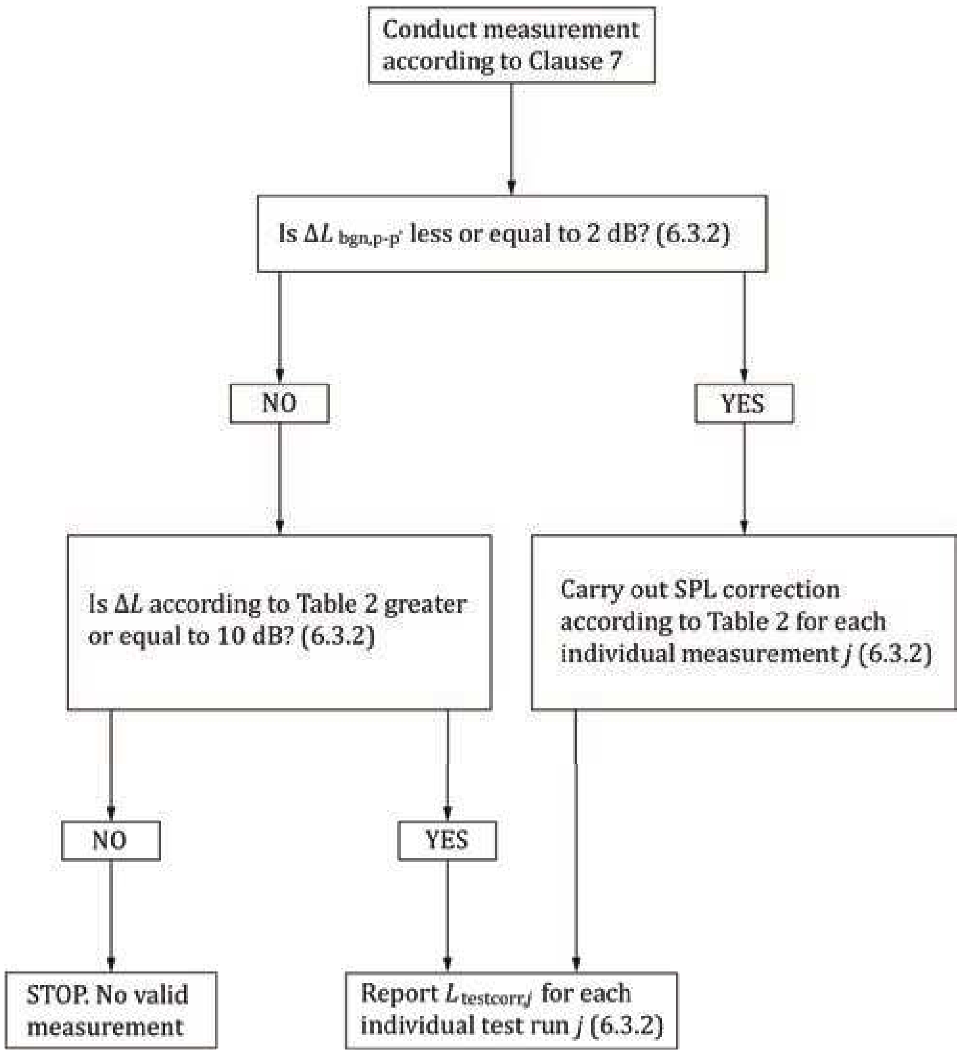


Figure H.1 — Vehicle A-weighted sound pressure level measurement correction criteria

Annex I
(informative)

Flowchart for the procedure to report A-weighted one-third-octave-band sound pressure levels

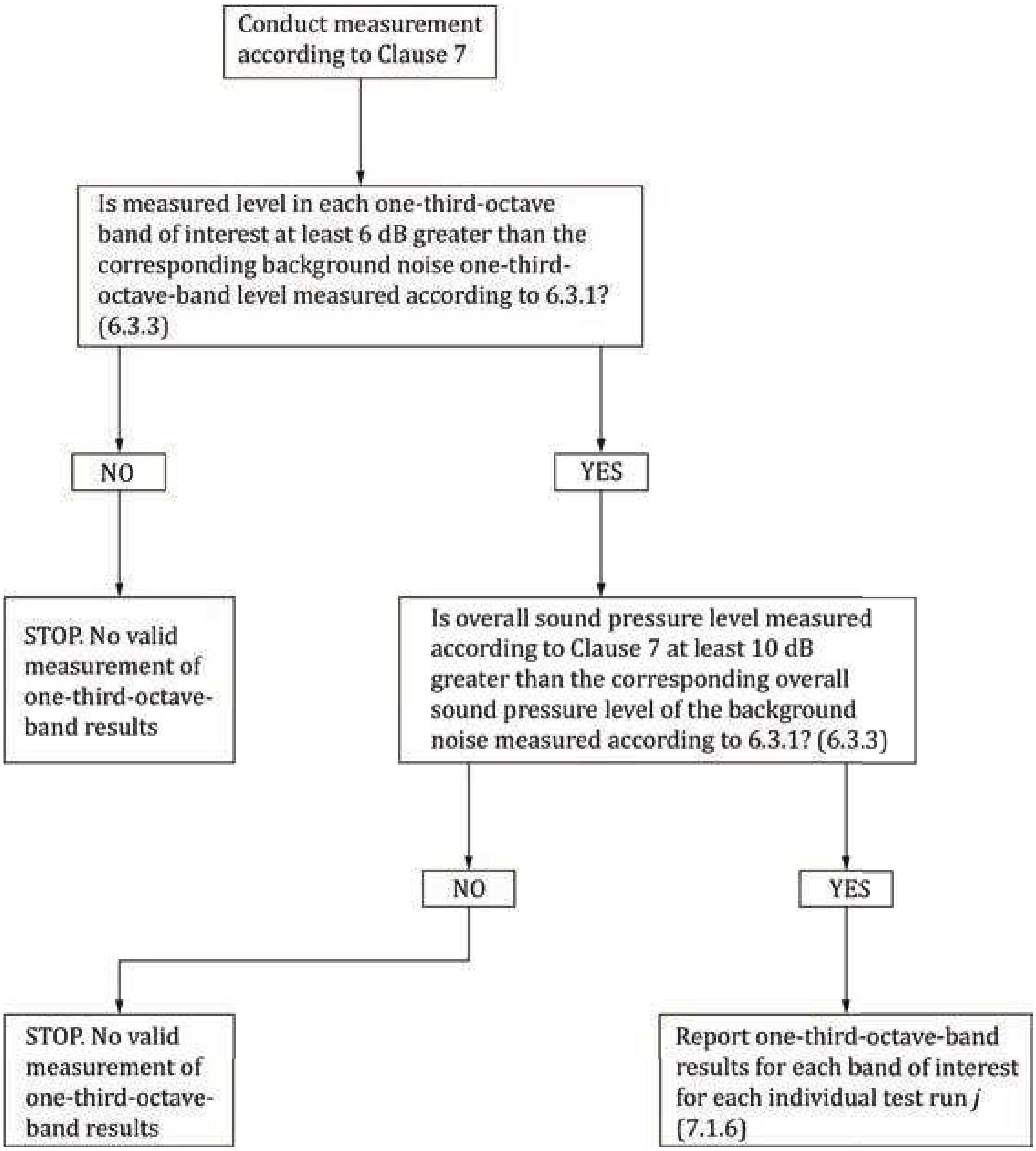


Figure I.1 — Background noise requirements for analysis in one-third-octave bands

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